Reheating and Primordial Gravitational Waves in Generalized Galilean Genesis

Sakine Nishi (Rikkyo University)
in collaboration with Tsutomu Kobayashi (Rikkyo University)

[S. Nishi, T. Kobayashi, [arxiv: 1501.02553 [hep-th]]
[S. Nishi, T. Kobayashi, [arxiv: 1601.06561 [hep-th]]

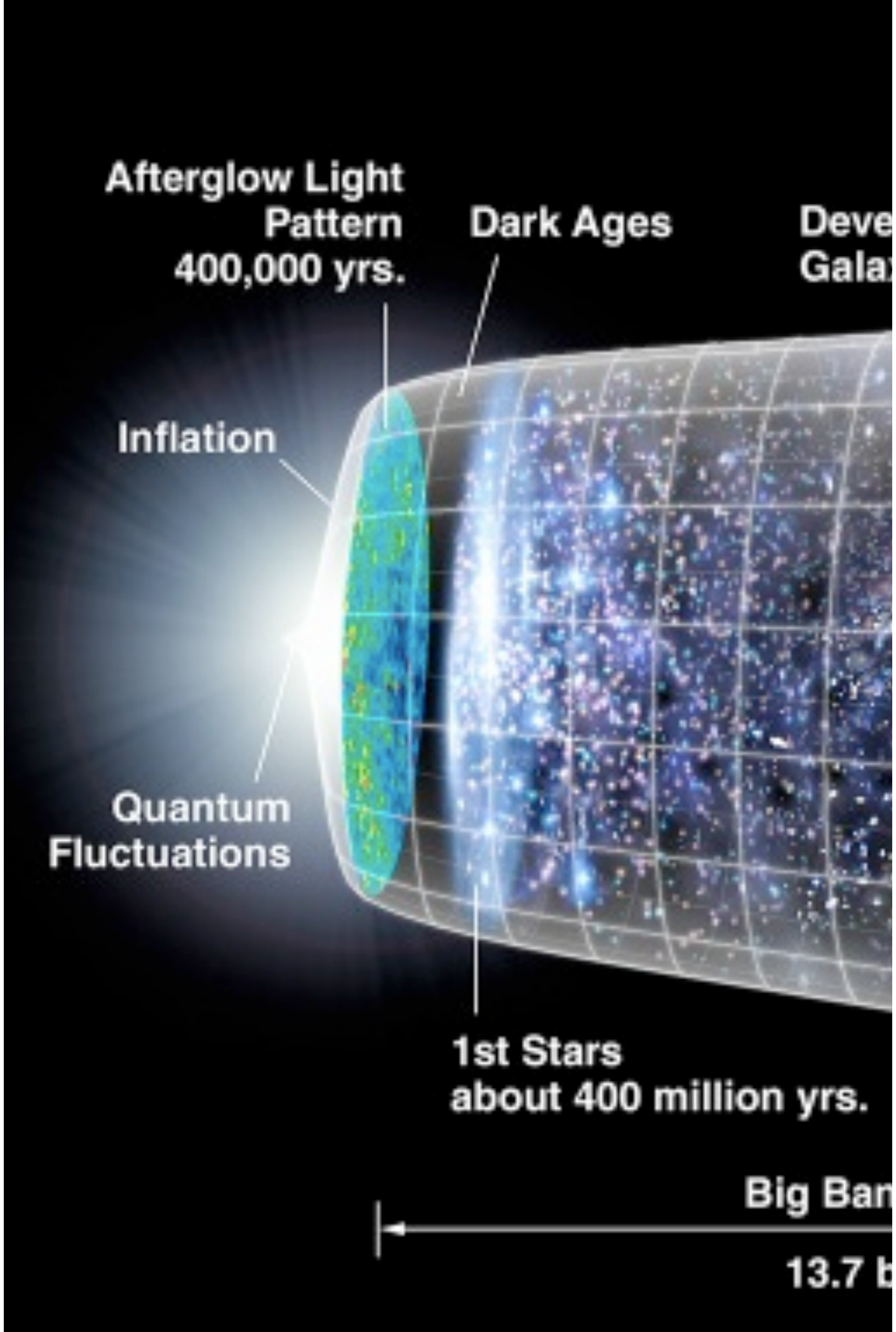
March 30 @IPMU

Outline

- **Introduction**
- Original model of Galilean Genesis
- Generalized Galilean Genesis
- Reheating phase
- Gravitational waves
- Conclusions

Introduction

- There are many kinds of models which explain the early universe.
- Inflation explains the observational result well.
- Galilean Genesis is an alternative to Inflation.



Galilean Genesis - Horndeski theory

- The most general scalar-tensor theory
- Field eqs. have no 3rd and higher derivative terms
- Generalized Galilean Genesis is subclass of this theory.

$$S_{\mathrm{Hor}} = \int \mathrm{d}^4x\sqrt{-g}\Big\{G_2(\phi,X) - G_3(\phi,X)\Box\phi + G_4(\phi,X)R + G_{4X}\left[(\Box\phi)^2 - (\nabla_\mu\nabla_\nu\phi)^2\right] + G_5(\phi,X)G^{\mu\nu}\nabla_\mu\nabla_\nu\phi - \frac{1}{6}G_{5X}\left[(\Box\phi)^3 - 3\Box\phi(\nabla_\mu\nabla_\nu\phi)^2 + 2(\nabla_\mu\nabla_\nu\phi)^3\right]\Big\}$$

$$X := -g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi/2$$

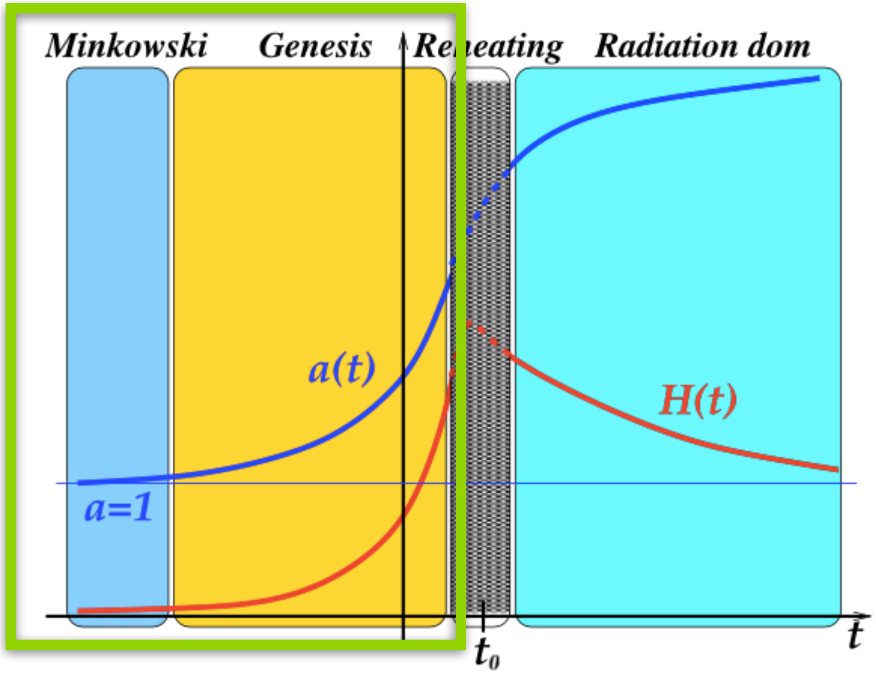
[G. W. Horndeski (1974)]
[T. Kobayashi, M. Yamaguchi and J. Yokoyama (2011)]

Introduction - motivation

○ **Only inflation can explain the early universe?**
compare genesis to the other inflation models and discuss observational implications.

In the previous study…

- Background evolution
- Perturbations
  - Scalar, Tensor



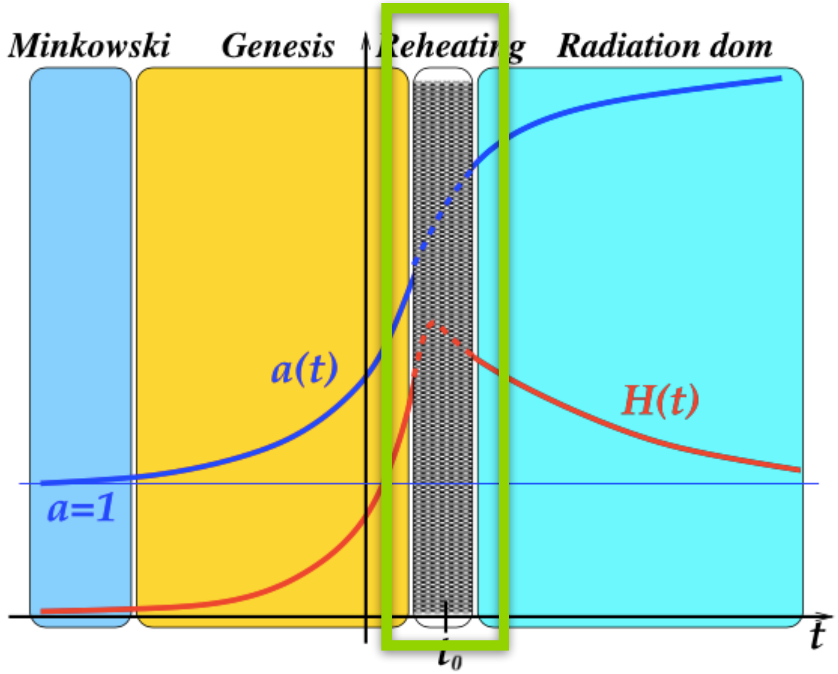
[P. Creminelli, A. Nicolis and E. Trincherini (2010)]

Introduction - motivation

- **Only inflation can explain the early universe?**
  compare genesis to the other inflation models and discuss observational implications.

In this talk…

- Matter creation
- Gravitational Waves



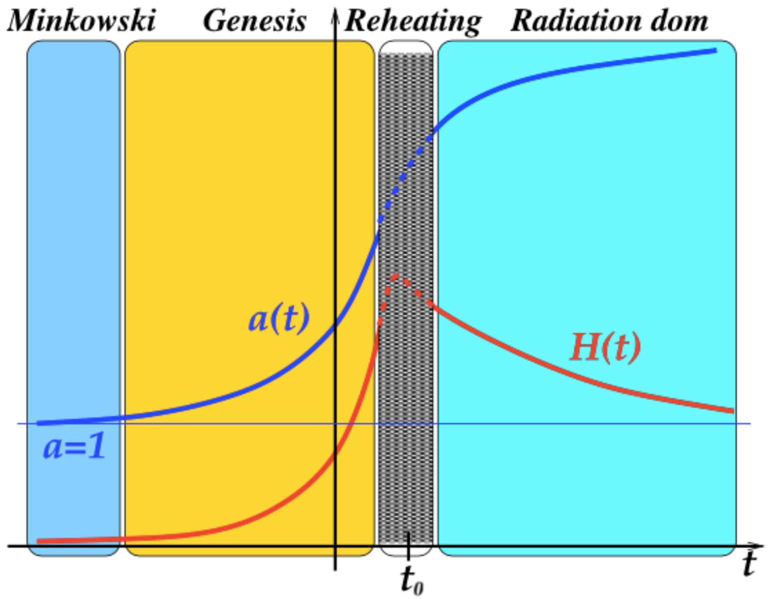
[P. Creminelli, A. Nicolis and E. Trincherini (2010)]

Outline

- Introduction
- **Original model of Galilean Genesis**
- Generalized Galilean Genesis
- Reheating phase
- Gravitational waves
- Conclusions

Galilean Genesis - Previous work

- Alternative to inflation model
- Null Energy Condition is violated stably



- Previous work
  - action

$$\mathcal{S} = \int \mathrm{d}x^4 \sqrt{-g}\left[f^2 e^{2\phi}(\partial\phi)^2 + \frac{f^3}{\Lambda^3}(\partial\phi)^2\Box\phi + \frac{f^3}{2\Lambda^3}(\partial\phi)^4\right]$$

[P. Creminelli, A. Nicolis and E. Trincherini, JCAP **1011**, 021 (2010)]

Galilean Genesis - Previous work

- solutions

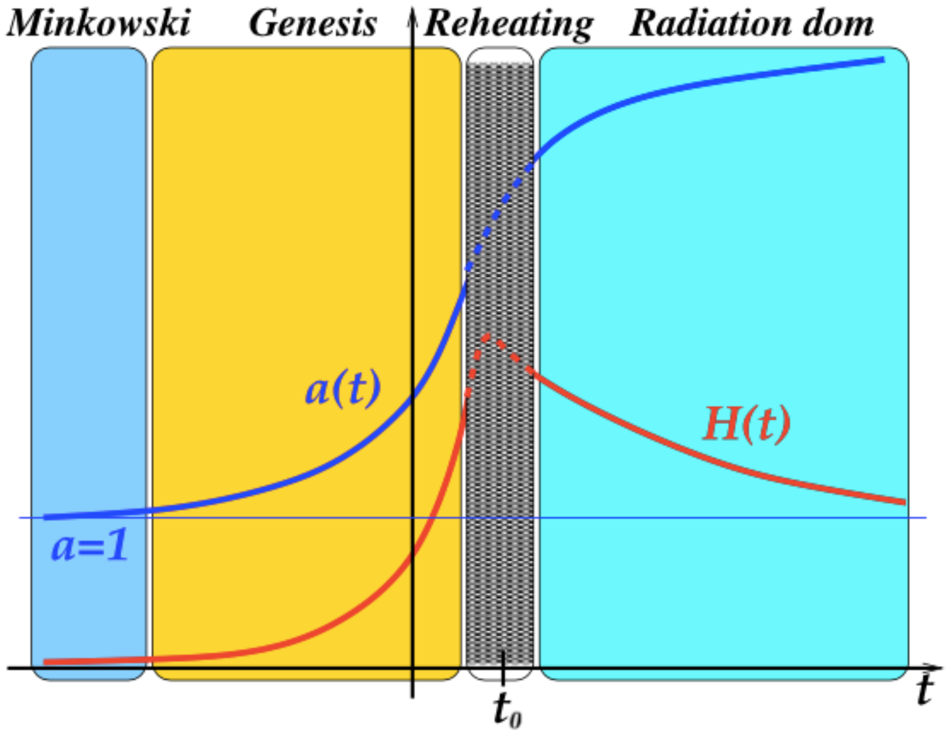
$t \to -\infty$

$$e^{\lambda\phi} \propto (-t)^{-1}$$

$$H(t) \simeq -\frac{f^2}{3M_{Pl}^2}\frac{1}{H_0^2 t^3}$$

$$a(t) \simeq 1$$

-> Minkowski space-time



$t \to t_0$ (numerical analysis)

$$a(t) = \exp\left[\frac{8f^2}{3H_0^2 M_{Pl}^2}\frac{1}{(t_0-t)^2}\right] \qquad H(t) \simeq \frac{16f^2}{3M_{Pl}^2}\frac{1}{H_0^2(t_0-t)^3}$$

[P. Creminelli, A. Nicolis and E. Trincherini, JCAP **1011**, 021 (2010)]

Outline

- Introduction
- Original model of Galilean Genesis
- **Generalized Galilean Genesis**
- Reheating phase
- Gravitational waves
- Conclusions

Galilean Genesis - Generalized model

- include the various models of Genesis

- parameter α
  arbitrary function $g_i(Y)$

$$G_2 = e^{2(\alpha+1)\lambda\phi} g_2(Y), \quad G_3 = e^{2\alpha\lambda\phi} g_3(Y),$$
$$G_4 = \frac{M_{\rm Pl}^2}{2} + e^{2\alpha\lambda\phi} g_4(Y), \quad G_5 = e^{-2\lambda\phi} g_5(Y). \quad Y := e^{-2\lambda\phi} X$$

- Example - Original model

$$g_2 = 2f^2 Y + 2\frac{f^3}{\Lambda^3} Y^2, \quad g_3 = 2\frac{f^3}{\Lambda^3} Y, \quad g_4 = g_5 = 0, \quad \alpha = \lambda = 1$$

[S. Nishi, T. Kobayashi, (2015)]

Galilean Genesis

solutions $(-\infty < t < 0)$

- Friedmann eq. $\mathcal{E} \simeq e^{2(\alpha+1)\lambda\phi}\hat{\rho}(Y_0) \simeq 0$

$$\hat{\rho}(Y) := 2Yg_2' - g_2 - 4\lambda Y\left(\alpha g_3 - Yg_3'\right)$$

- $\hat{\rho} = 0$ $\qquad Y_0 = e^{-2\lambda\phi}X = const.$

$$e^{\lambda\phi} \propto (-t)^{-1}\ , \quad H(t) \propto \frac{1}{(-t)^{2\alpha+1}}, \quad a \simeq a_G\left[1 + \frac{1}{2\alpha}\frac{h_0}{(-t)^{2\alpha}}\right]$$

- Evolution eq.

$$\mathcal{P} \simeq 2\mathcal{G}(Y_0)\dot{H} + e^{2(\alpha+1)\lambda\phi}\hat{p}(Y_0) \simeq 0$$

NEC violated

$\hat{p} < 0$

Galilean Genesis

solutions $(-\infty < t < 0)$

- Friedmann eq. $\mathcal{E} \simeq e^{2(\alpha+1)\lambda\phi}\hat{\rho}(Y_0) \simeq 0$

$$\hat{\rho}(Y) := 2Yg_2' - g_2 - 4\lambda Y\,(\alpha g_3 - Yg_3')$$

- $\hat{\rho} = 0$ $\quad Y_0 = e^{-2\lambda\phi}X = const.$

higher order of t^-1

$$e^{\lambda\phi} \propto (-t)^{-1}\,,\quad H(t) \propto \frac{1}{(-t)^{2\alpha+1}},\quad a \simeq a_G\left[1 + \frac{1}{2\alpha}\frac{h_0}{(-t)^{2\alpha}}\right] + \cdots$$

- Evolution eq.

$$\mathcal{P} \simeq 2\mathcal{G}(Y_0)\dot{H} + e^{2(\alpha+1)\lambda\phi}\hat{p}(Y_0) \simeq 0$$

NEC violated

$\hat{p} < 0$

Background

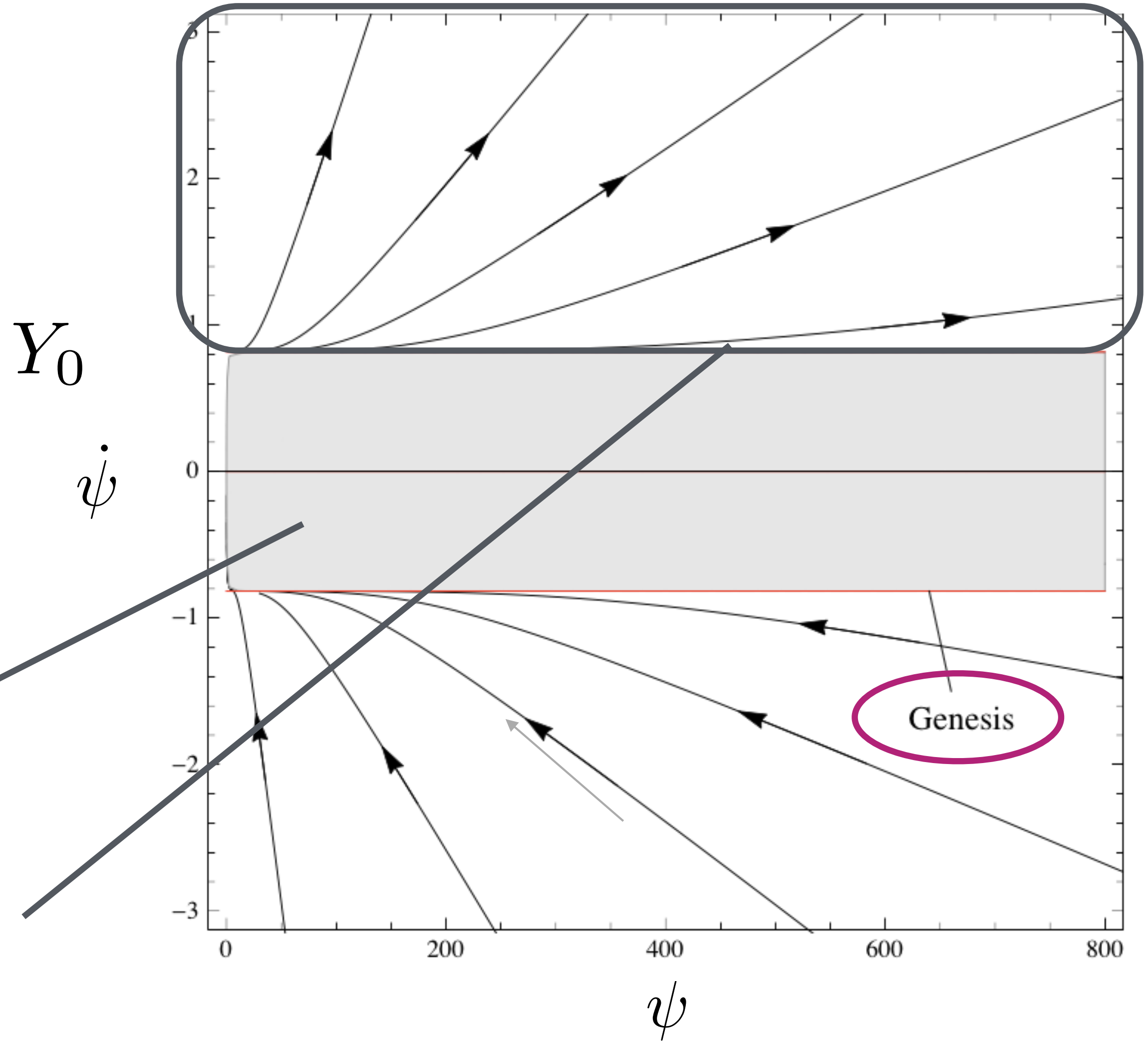
- Numerical analysis

$$\alpha = 1$$
$$g_2 = -Y + Y^2$$
$$g_3 = Y$$
$$g_4 = 0$$
$$g_5 = 0$$

corresponding to

-> $\psi = e^{-\lambda\phi}$

$$Y_0 \propto \dot{\psi}$$



no solution of H(t)

time reversal solutions

Perturbation (tensor)

Action

$$\mathcal{S}_T^{(2)} = \frac{1}{8}\int \mathrm{d}t\mathrm{d}^3x a^3 \left[\mathcal{G}_T \dot{h}_{ij}^2 - \frac{\mathcal{F}_T}{a^2}(\nabla^2 h_{ij})^2\right]$$

$$\simeq const.$$

-> in Minkowski spacetime fluctuation do not grow

-> too small to detect…

Stability

sound speed -> $c_t^2 = \frac{\mathcal{F}_T}{\mathcal{G}_T} = \frac{M_{\mathrm{Pl}}^2 + 4\lambda Y_0 g_5(Y_0)}{\mathcal{G}(Y_0)}$

$$\mathcal{G}(Y_0) > 0, \quad M_{\mathrm{Pl}}^2 + 4\lambda Y_0 g_5(Y_0) > 0$$

Perturbation (scalar)

- Lagrangian

$$\mathcal{L}_\zeta = \mathcal{A}(Y_0)(-t)^{2\alpha}\left[\dot{\zeta}_k^2 - k^2 c_s^2 \zeta_k^2\right]$$

- Wave eq.

$$\ddot{\zeta}_k - \frac{2\alpha}{(-t)}\dot{\zeta}_k + k^2 c_s^2 \zeta_k = 0$$

- solution

$$\zeta_k = \frac{1}{2}\sqrt{\frac{\pi}{\mathcal{A}(Y_0)}}(-t)^\nu H_\nu^{(1)}(\omega_k(-t)), \quad \nu = \frac{1}{2} - \alpha$$

- $0 < \alpha < \frac{1}{2}$: decaying mode + const.
- $\alpha > \frac{1}{2}$: growing mode + const.

Perturbation (scalar)

- $0 < \alpha < \frac{1}{2}$

$$\mathcal{P}_\zeta(k) = \frac{c_s^{-2\nu} 2^{2\nu-2} \Gamma(\nu)^2}{\pi^3 \mathcal{A}(Y_0)} k^{3-2\nu}$$

$$n_s = 2\alpha + 3$$

- $\alpha > \frac{1}{2}$

$$\mathcal{P}_\zeta(k) = \frac{c_s^{2\nu} 2^{-2\nu-3} \Gamma(\nu)^2 (-t_{end})^4}{\pi^3 \mathcal{A}(Y_0)} k^{3+2\nu}$$

$$n_s = 5 - 2\alpha$$

genesis phase ends at t_{end}

- $\alpha = 2$: flat spectrum
- $\alpha \neq 2$: introducing the curvaton field

Perturbation (scalar)

- Stability
  - Lagrangian

$$\mathcal{L}_\zeta = \mathcal{A}(Y_0)(-t)^{2\alpha}\left[\dot{\zeta}_k^2 - k^2 c_s^2 \zeta_k^2\right]$$

  - sound speed

$$c_s^2 = \frac{\mathcal{F}_s}{\mathcal{G}_s} = \frac{\xi'(Y_0)\hat{p}(Y_0)}{\xi(Y_0)\hat{\rho}'(Y_0)} = const., \quad \xi(Y) := -\frac{Y\mathcal{G}(Y)}{\hat{p}(Y)}$$

->

$$\hat{\rho}'(Y_0) > 0, \quad \xi'(Y_0) < 0$$

Outline

- Introduction
- Original model of Galilean Genesis
- Generalized Galilean Genesis
- **Reheating phase**
- Gravitational waves
- Conclusions

Matter Creation - scenario

- Massless scalar field matter χ is generated.

$$\mathcal{L}_\chi = -\frac{1}{2} g^{\mu\nu} \partial_\mu \chi \partial_\nu \chi$$

- Genesis at the end of genesis

$$a \simeq a_G \left[1 + \frac{1}{2\alpha} \frac{h_0}{(-t)^{2\alpha}} \right]$$

$$\frac{1}{2\alpha} \frac{h_0}{(-t)^{2\alpha}} = \delta_* \ll 1$$

↓

Kination

$$\mathcal{L} \simeq \frac{M_{Pl}^2}{2} R + X$$ (X : Kinetic term)

Matter Cre

- Massless s
- Genesis

↓

Kination

How $\mathcal{L}$ changes ?

introduce ↓ in $g_2(Y)$

$$S = \int d^4x \sqrt{-g}\left[\frac{1}{2}M_{\rm Pl}^2 R + f^2 \frac{e^{2\pi}}{1+\beta e^{2\pi}}(\partial\pi)^2 + \frac{f^3}{\Lambda^3}(\partial\pi)^2\Box\pi + \frac{f^3}{2\Lambda^3}(\partial\pi)^4\right]$$

[D. Pirtskhalava, L. Santoni, E. Trincherini, P. Uttayarat (2014)]

$$= \delta_* \ll 1$$

$$\mathcal{L} \simeq \frac{M_{Pl}^2}{2} R + X$$ (X : Kinetic term)

time

Genesis | Kination | Radiation

Matter Creation - scenario

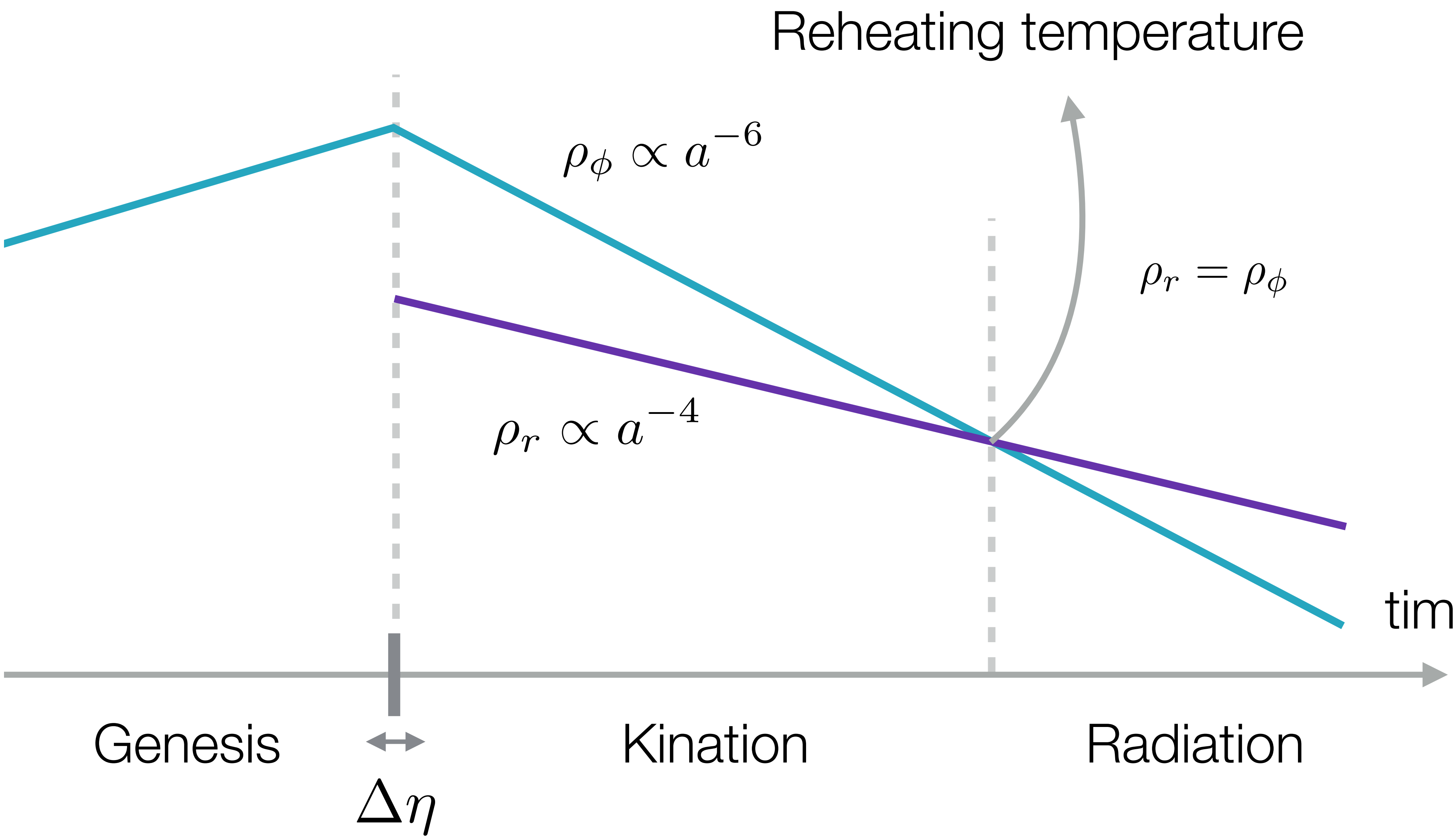
- Scalar field ϕ (generate the Genesis phase)
  in kination phase

$$\rho_\phi \propto a^{-6} \quad \longleftarrow \quad \mathcal{L} \simeq \frac{M_{Pl}^2}{2} R + X$$

- Scalar field χ (created matter)
  energy density of radiation

$$\rho_r \propto a^{-4} \quad \longleftarrow \quad \rho_\chi = \frac{1}{2\pi^2 a^4} \int_0^\infty k^3 \left|\beta_k(\infty)\right|^2 \mathrm{d}k$$

Matter Creation - scenario



Matter Creation

- Solution of χ

$$a(\eta)\chi_k(\eta) = \frac{\alpha_k(\eta)}{\sqrt{2k}} e^{ik\eta} + \frac{\beta_k(\eta)}{\sqrt{2k}} e^{-ik\eta}$$

- Definition of β_k and energy density

$$\beta_k(\eta) = -\frac{i}{2k}\int_{-\infty}^{\eta} e^{-2iks}\frac{a''}{a}\mathrm{d}s \qquad \rho_\chi = \frac{1}{2\pi^2 a^4}\int_0^\infty k^3 \left|\beta_k(\infty)\right|^2 \mathrm{d}k$$

$$\rho_\chi = -\frac{1}{128\pi^2 a^4}\int_{-\infty}^{\infty}\mathrm{d}\eta_1 \int_{-\infty}^{\infty}\mathrm{d}\eta_2 \ln(m|\eta_1 - \eta_2|) V'(\eta_1) V'(\eta_2)$$

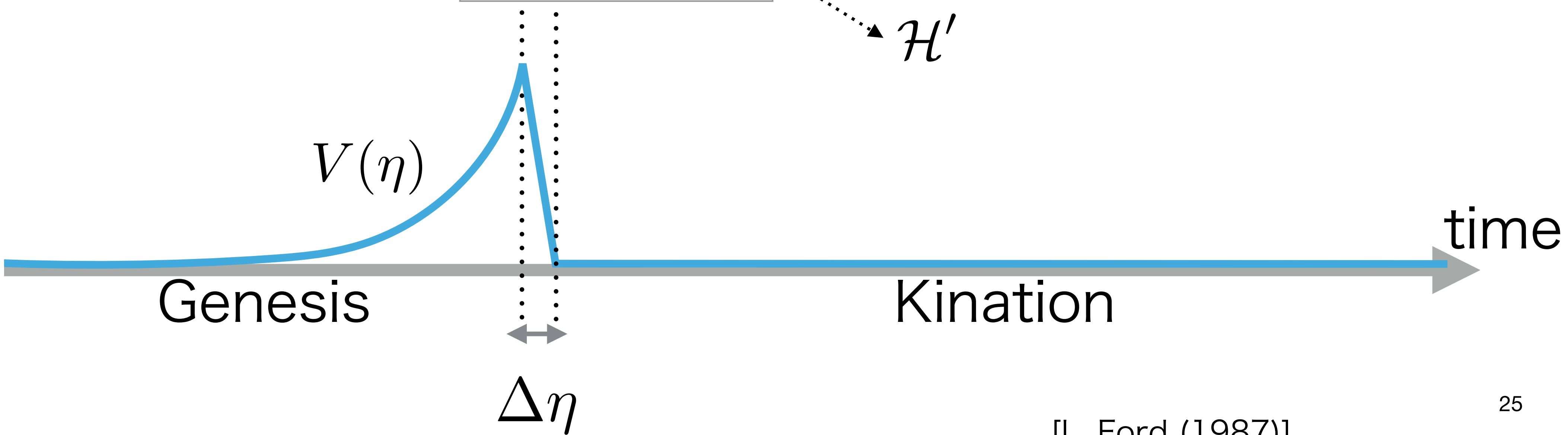
[L. Ford (1987)]

Matter Creation

$$\rho_\chi = -\frac{1}{128\pi^2 a^4}\int_{-\infty}^{\infty} \mathrm{d}\eta_1 \int_{-\infty}^{\infty} \mathrm{d}\eta_2 \ln(m|\eta_1-\eta_2|)V^{'}(\eta_1)V^{'}(\eta_2)$$

- genesis ends at $\eta = \eta_*$
  kination starts at $\eta = \eta_* + \Delta\eta$

- seek $V(\eta) = \boxed{\frac{f'' f - (f')^2/2}{f^2}}$ $\quad f(\eta) := a^2(\eta)$



[L. Ford (1987)]

Matter Creation

$$\rho_r = -\frac{1}{128\pi^2 a^4}\int_{-\infty}^{\infty} d\eta_1 \int_{-\infty}^{\infty} d\eta_2 \ln(m|\eta_1-\eta_2|)V'(\eta_1)V'(\eta_2)$$

- assume

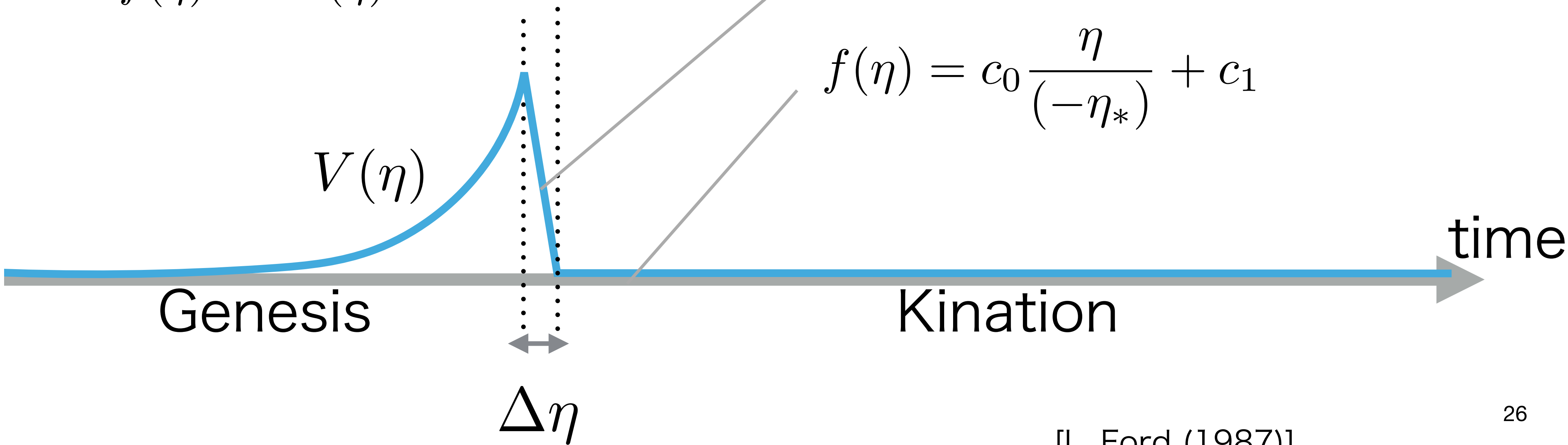
$$V(\eta) = \frac{f''f-(f')^2/2}{f^2}$$

$$f(\eta) := a^2(\eta)$$

$V(\eta)$ approximately a straight line

$$f(\eta) = b_0 + b_1\eta + b_2\eta^2 + b_3\eta^3$$

$$f(\eta) = c_0\frac{\eta}{(-\eta_*)} + c_1$$



[L. Ford (1987)]

Matter Creation

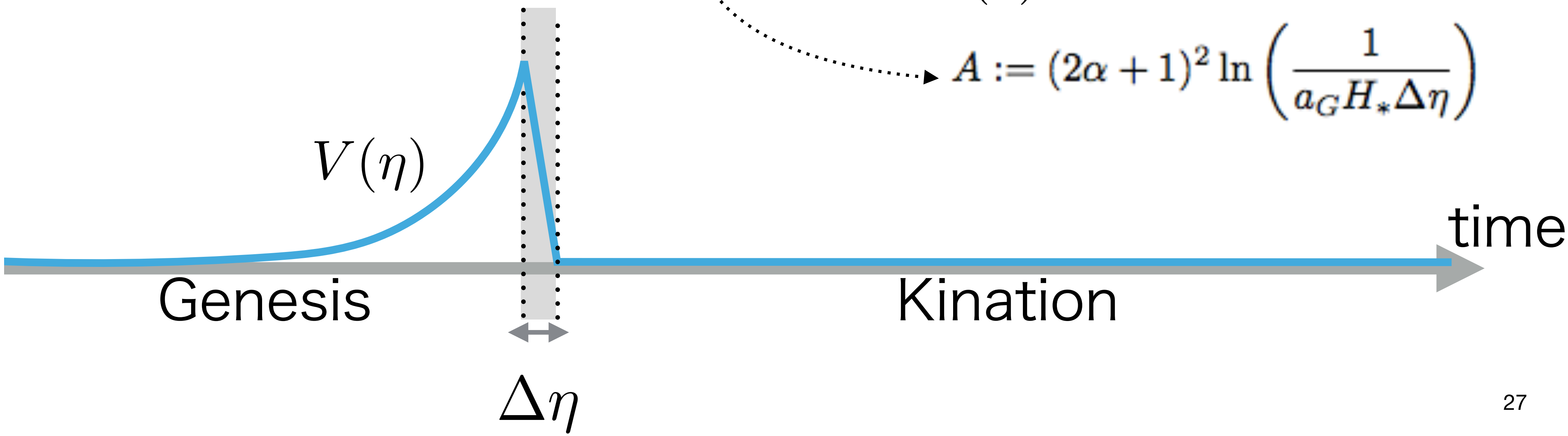
- Therefore…

  Matter χ is generated in $\Delta\eta$

$$\rho_\chi = \frac{(2\alpha+1)^2}{32\pi^2} \ln\left(\frac{1}{a_G H_* \Delta\eta}\right) \frac{h_0^2}{(-t_*)^{4(\alpha+1)}} \left(\frac{a_G}{a}\right)^4$$

assume $\mathcal{O}(1)$

$$A := (2\alpha+1)^2 \ln\left(\frac{1}{a_G H_* \Delta\eta}\right)$$

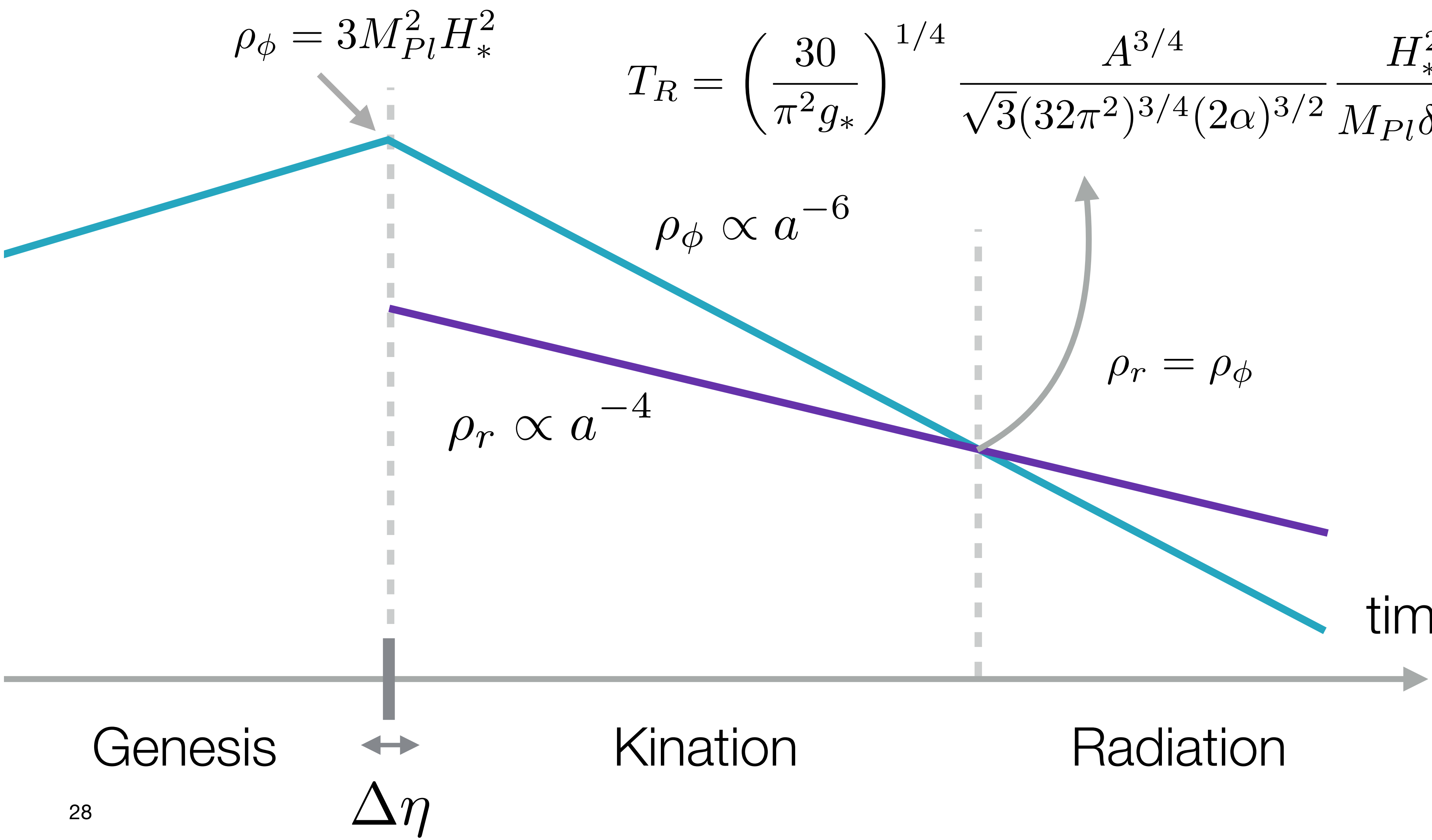


Matter Creation

in inflation $T_R \sim \frac{H_{inf}^2}{M_{Pl}}$

Reheating temperature

$$T_R = \left(\frac{30}{\pi^2 g_*}\right)^{1/4} \frac{A^{3/4}}{\sqrt{3}(32\pi^2)^{3/4}(2\alpha)^{3/2}} \frac{H_*^2}{M_{Pl}\delta_*^{3/2}}$$



Matter Creation - summary

- massless scalar generated in $\Delta\eta$

- How we set the end of genesis ($\eta = \eta_*$) determine ρ_χ and T_R .

- H_* of genesis can be smaller than that of inflation.

Outline

- Introduction
- Original model of Galilean Genesis
- Generalized Galilean Genesis
- Reheating phase
- **Gravitational waves**
- Conclusions

Gravitational Waves - previous study

- from the quadratic action

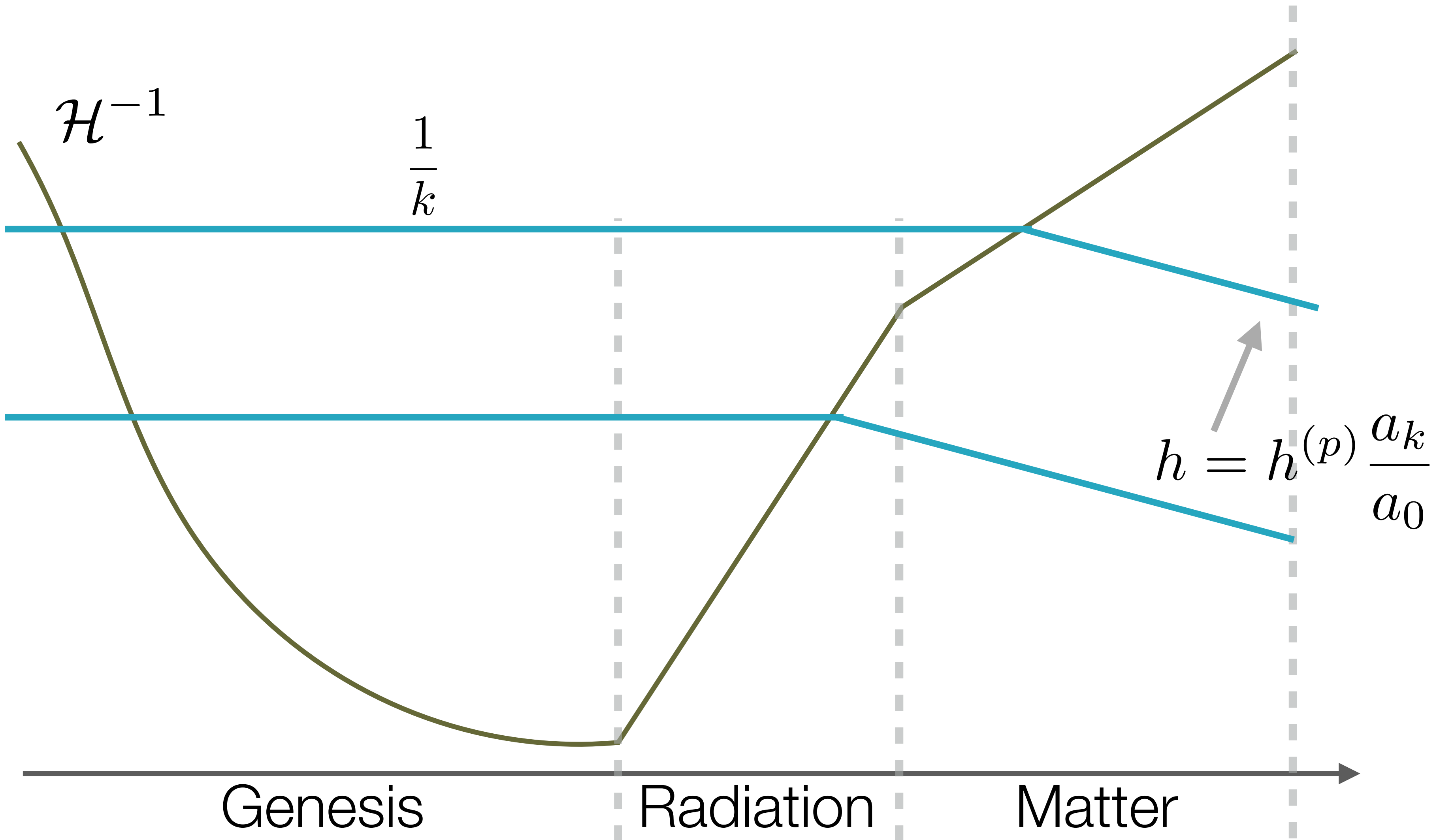
$$\mathcal{S}_T^{(2)} = \frac{1}{8}\int \mathrm{d}t\mathrm{d}^3x a^3 \left[\mathcal{G}_T \dot{h}_{ij}^2 - \frac{\mathcal{F}_T}{a^2}(\nabla^2 h_{ij})^2\right]$$

$$\simeq const.$$

in Minkowski space-time GWs do not grow
→ too small to detect

- In this study…
  Power spectrum grows during high frequency area In this scenario.

Gravitational Waves



Gravitational Waves - power spectrum

- Power spectrum

Horizon cross

$$\Omega_{\rm gw} = \Omega_{\rm gw}^{(p)}(k) \times \begin{cases} \frac{k_R}{k}\frac{k_{\rm eq}^2}{k_R^2}\frac{k_0^4}{k_{\rm eq}^4} & (k_R < k < k_*) \\ \frac{k_{\rm eq}^2}{k^2}\frac{k_0^4}{k_{\rm eq}^4} & (k_{\rm eq} < k < k_R) \\ \frac{k_0^4}{k^4} & (k_0 < k < k_{\rm eq}) \end{cases}$$

Kination

Radiation

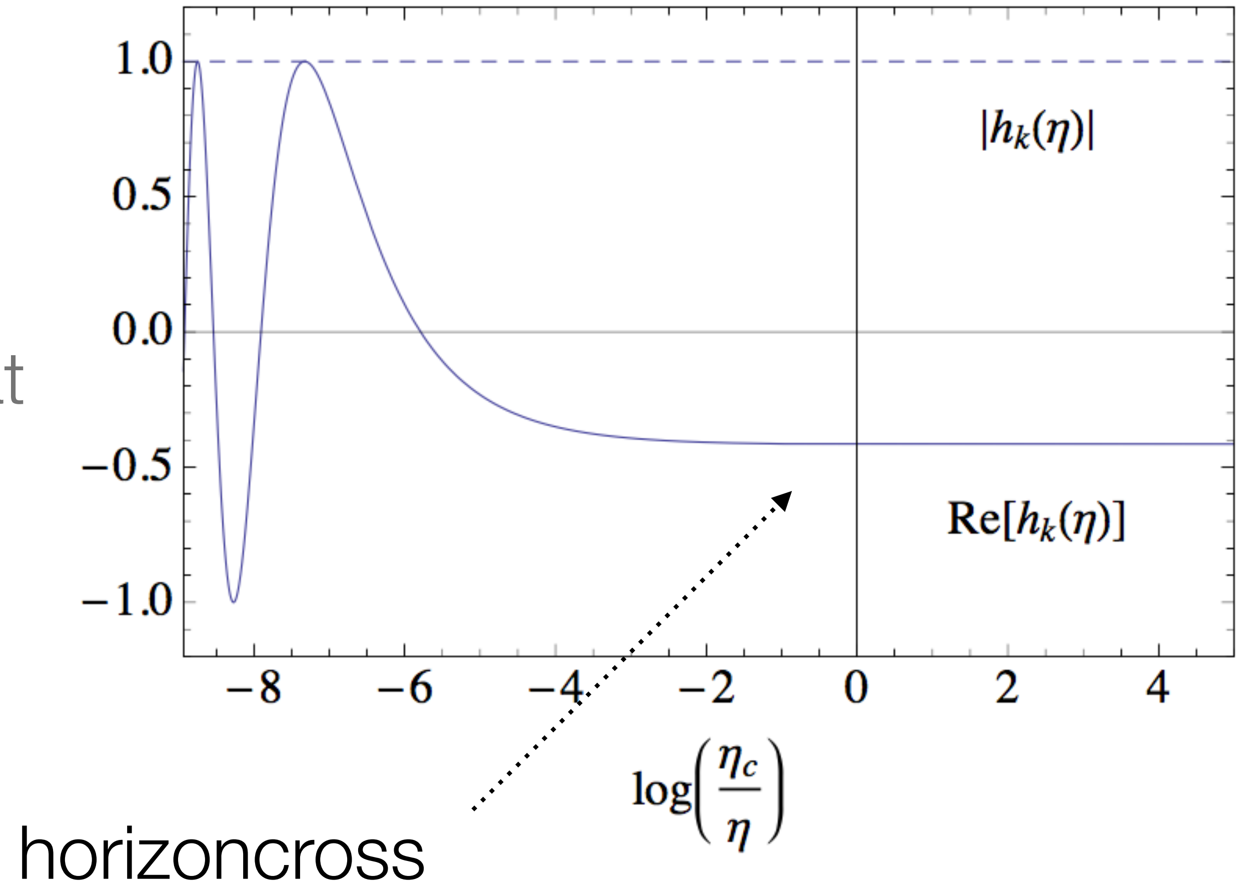
Matter

Gravitational Waves

- h_k do not grow in genesis.

$$h_k = \frac{1}{a}\sqrt{\frac{2}{\mathcal{G}c_t k}}e^{-ic_t k\eta}$$

- $|h_k|$ do not change at the horizoncross.



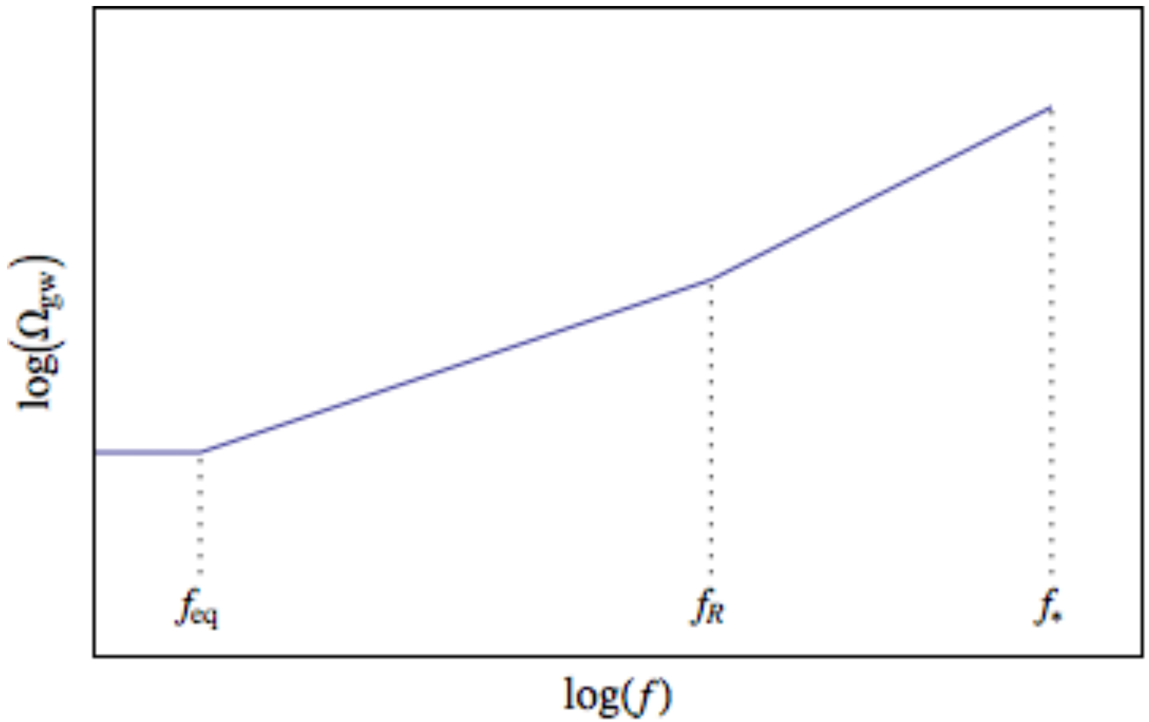
Gravitational Waves

$$\Omega_{\rm gw} = \begin{cases} \propto k^3 & (k_R < k < k_*) \\ \propto k^2 & (k_{\rm eq} < k < k_R) \\ \text{const.} & (k_0 < k < k_{\rm eq}) \end{cases}$$

↓

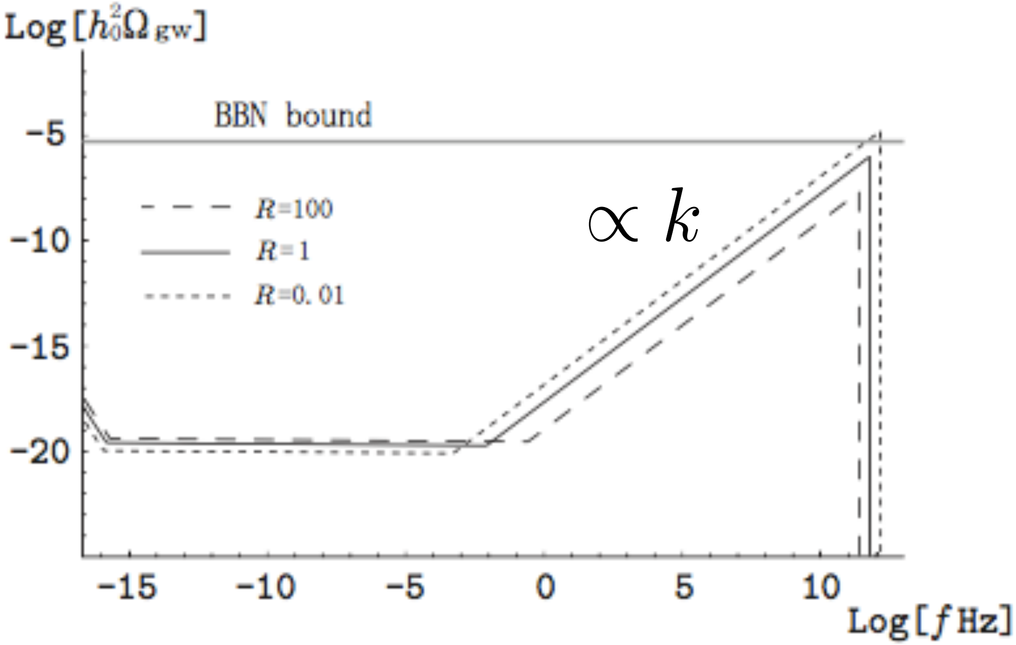
$$\Omega_{gw}(k_R) \simeq \frac{\delta_*^2 T_R^4}{M_{Pl}^2 H_*^2} \times 10^{-2}$$

$$\Omega_{gw}(k_*) \simeq \frac{H_*^5}{M_{Pl}^3 \delta_*^2 T_R^2} \times 10^{-7}$$

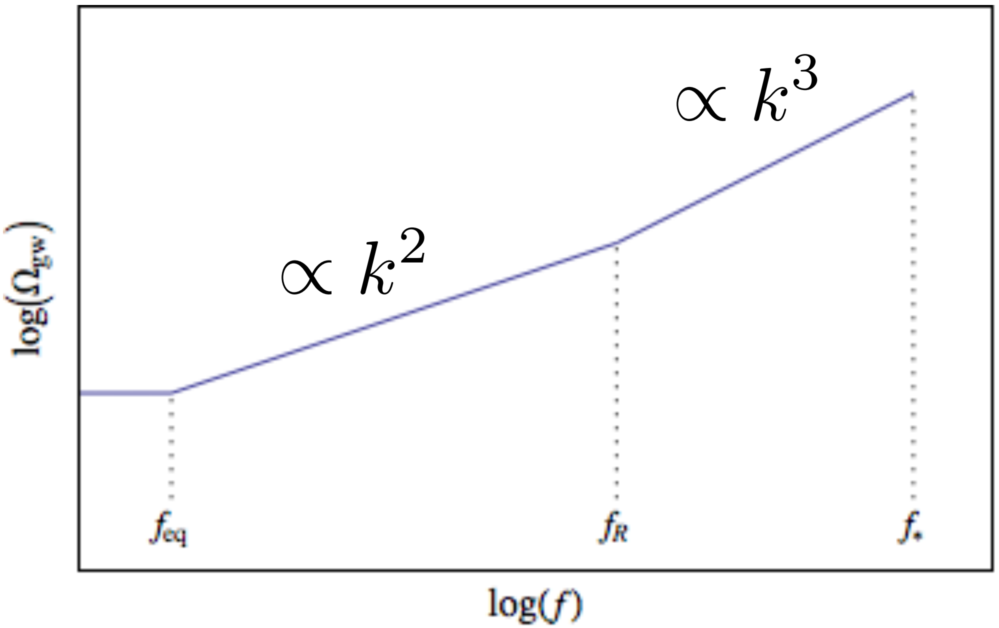


Gravitational Waves

- Inflation
- Genesis



[H. Tashiro, T. Chiba, M. Sasaki, (2012)]



Gravitational Waves

- genesis

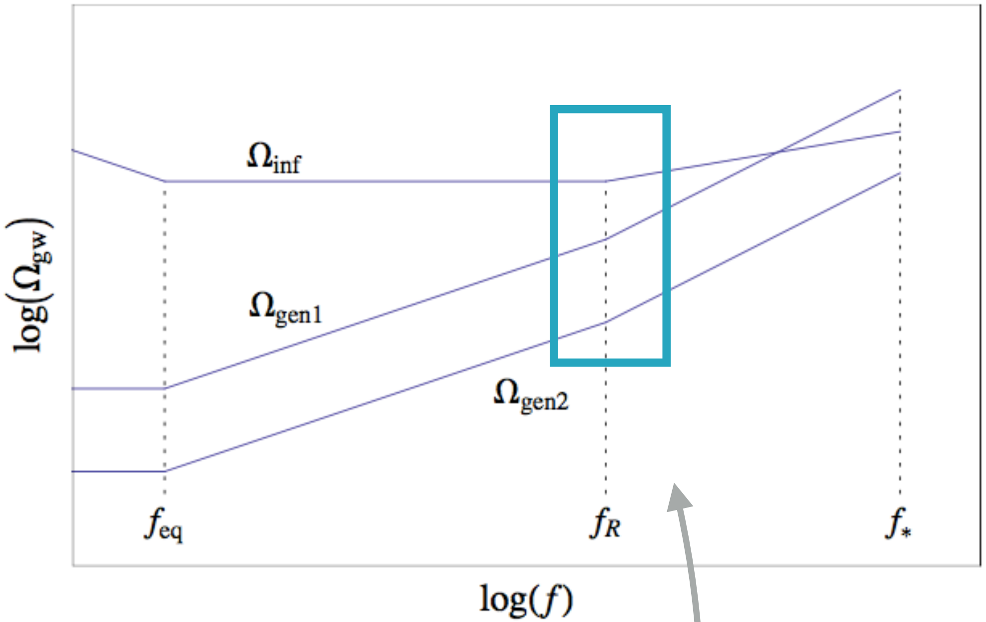
$$\Omega_{gw}(k_R) \simeq \left(\frac{H_*}{M_{Pl}}\right)^2 \left(\frac{a_R}{a_G}\right)^{-4} \times 10^{-5}$$

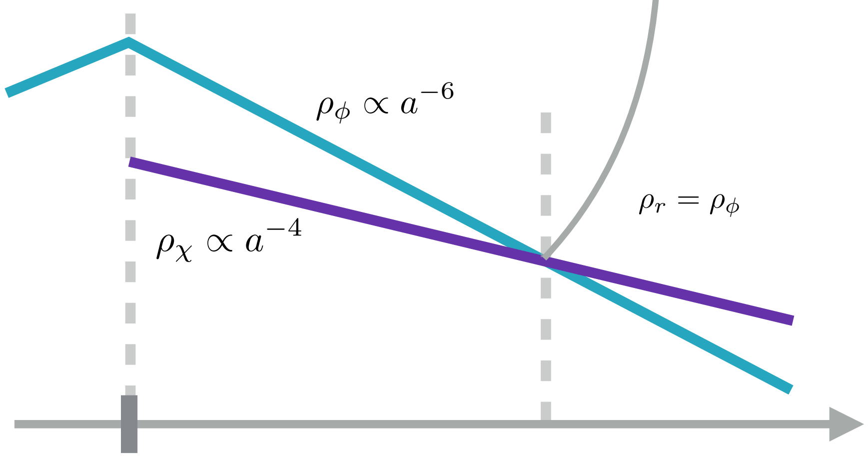
$$\Omega_{gw}(k_*) \simeq \left(\frac{H_*}{M_{Pl}}\right)^2 \left(\frac{a_R}{a_G}\right)^{2} \times 10^{-5}$$

- inflation

$$\Omega_{gw}^{inf} \simeq \left(\frac{H_{inf}}{M_{Pl}}\right)^2 \times 10^{-5}$$

Ω_{gw}^{gen} can not be larger than Ω_{gw}^{inf}





Gravitational Waves

- General cases

$$\Omega_{\rm gw}(f) = 10^{-31} \cdot 3^{-\frac{1}{2+\alpha}} \left(\frac{32\pi^2}{A}\right)^{\frac{1+2\alpha}{2(2+\alpha)}} \left(\frac{\pi^2 g_*}{30}\right)^{\frac{1+\alpha}{2(2+\alpha)}} \tilde{h}^{\frac{1}{2+\alpha}} \left(\frac{T_R}{M_{pl}}\right)^{\frac{\alpha}{2+\alpha}} \left(\frac{f}{100\,\mathrm{Hz}}\right)^3$$

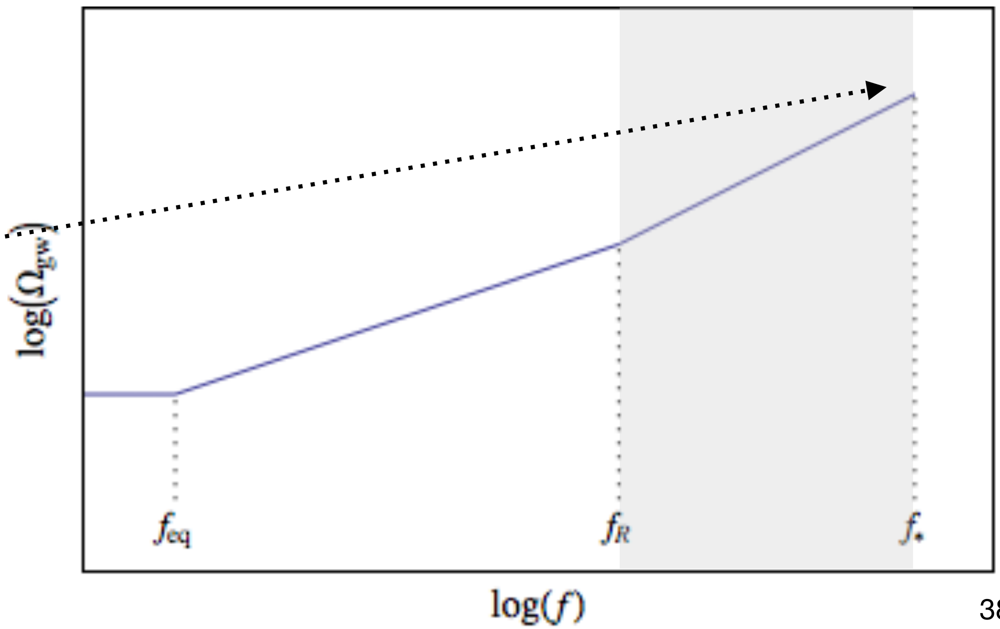
-> fix α and energy scales

in any model

$$\Omega_{gw} \sim 10^{-12}$$

$$f = 100\mathrm{MHz}$$

$$f_R \simeq 0.026 \left(\frac{g_*}{106.75}\right)^{1/6} \left(\frac{T_R}{10^6\,\mathrm{GeV}}\right) \mathrm{Hz}$$



Matter Creation - conditions

- for the end of genesis
  assume

$$h_0 = B M_{Pl}^{-2} \mu^{-2\alpha+2}$$

$$a \simeq a_G \left[1 + \frac{1}{2\alpha} \frac{h_0}{(-t)^{2\alpha}} \right]$$

$$= \delta_* \ll 1$$

$$\frac{H_*}{M_{Pl}} \ll B^{-1/2\alpha} \left(\frac{\mu}{M_{Pl}} \right)^{(\alpha-1)/\alpha}$$

- scale factor grows

$$a_R > a_G \quad \rightarrow \quad \frac{H_*}{M_{Pl}} < \left(\frac{96\pi^2}{A} \right)^{(2\alpha+1)/2} B \left(\frac{\mu}{M_{Pl}} \right)^{2(1-\alpha)}$$

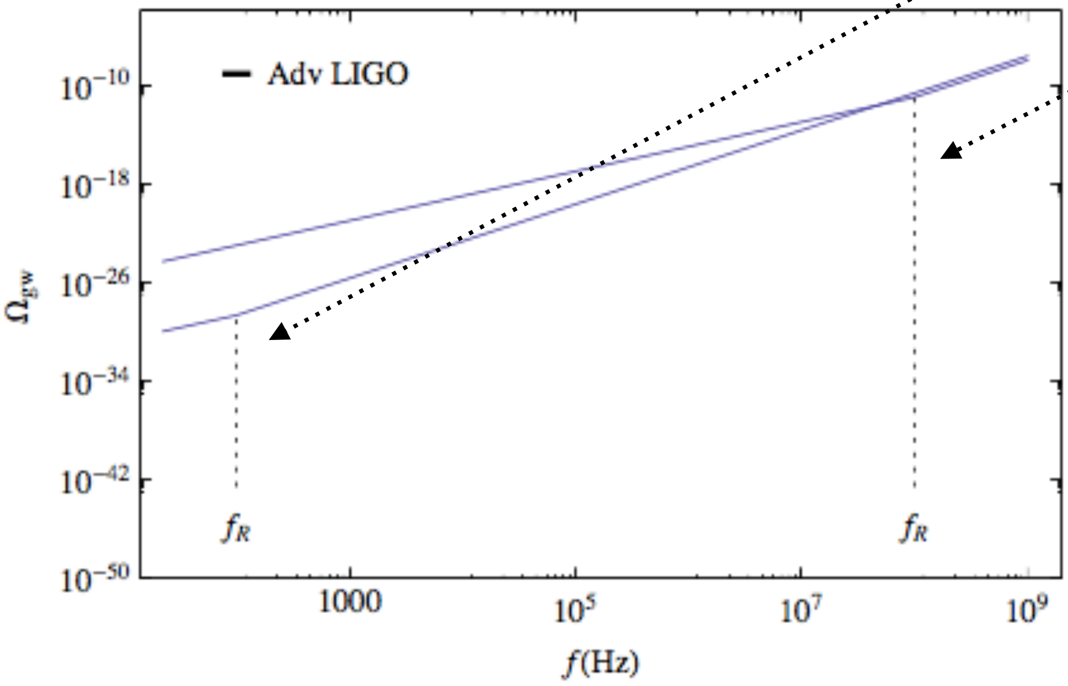
Gravitational Waves - example 1

- Original model

$$g_2 = -2f^2 Y + \frac{2f^3}{\Lambda^3} Y^2, \quad g_3 = \frac{2f^3}{\Lambda^3} Y,$$
$$g_4 = g_5 = 0, \quad \lambda = 1, \quad \alpha = 1,$$

$$\frac{\mu}{\Lambda} = 10^2 \quad \text{and} \quad T_R \sim 10^{10}\text{GeV}$$

$$\frac{\mu}{\Lambda} = 1 \quad \text{and} \quad T_R \sim 10^{16}\text{GeV}$$



$$\frac{H_*}{M_{Pl}} \ll B^{-1/2\alpha} \left(\frac{\mu}{M_{Pl}}\right)^{(\alpha-1)/\alpha}$$

$$\frac{H_*}{M_{Pl}} < \left(\frac{96\pi^2}{A}\right)^{(2\alpha+1)/2} B \left(\frac{\mu}{M_{Pl}}\right)^{2(1-\alpha)}$$

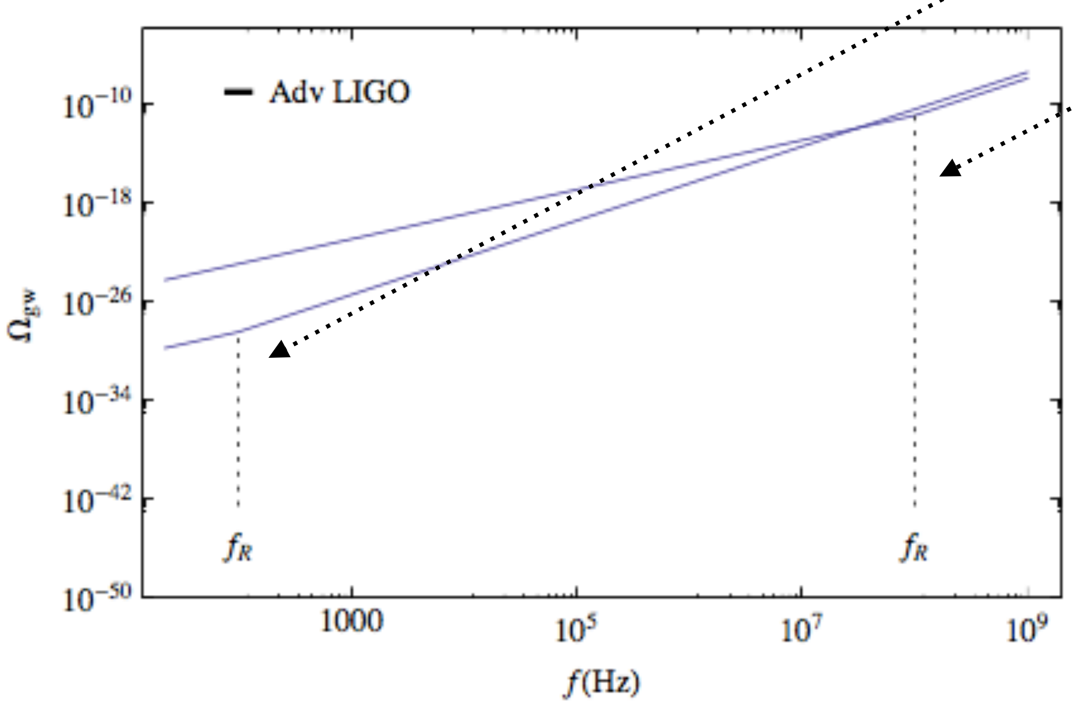
Gravitational Waves - example 2

- $\alpha = 2$ (the scale invariant curvature perturbation)

$$g_2 = 2f^2 Y + \frac{2f^3}{\Lambda^3} Y^2, \quad g_3 = \frac{2f^3}{\Lambda^3} Y,$$
$$g_4 = g_5 = 0, \quad \lambda = 1,$$

$$\frac{M_{Pl}\mu^2}{\Lambda^3} = 10^6 \quad \text{and} \quad T_R \sim 10^{10}\text{GeV}$$

$$\frac{M_{Pl}\mu^2}{\Lambda^3} = 1 \quad \text{and} \quad T_R \sim 10^{16}\text{GeV}$$



$$\frac{H_*}{M_{Pl}} \ll B^{-1/2\alpha} \left(\frac{\mu}{M_{Pl}}\right)^{(\alpha-1)/\alpha}$$

$$\frac{H_*}{M_{Pl}} < \left(\frac{96\pi^2}{A}\right)^{(2\alpha+1)/2} B \left(\frac{\mu}{M_{Pl}}\right)^{2(1-\alpha)}$$

Gravitational Waves

- density perturbation

$$\mathcal{P}_\zeta \simeq 10^{-11}\left(\frac{g_*}{106.75}\right)^{3/8}\left(\frac{M_{\rm Pl}\mu^2}{\Lambda^3}\right)^{1/2}\left(\frac{T_R}{10^{10}\,{\rm GeV}}\right)^{3/2} \quad \longrightarrow \quad \frac{M_{\rm Pl}\mu^2}{\Lambda^3} \sim 10^4\left(\frac{T_R}{10^{10}\,{\rm GeV}}\right)^{-3}$$

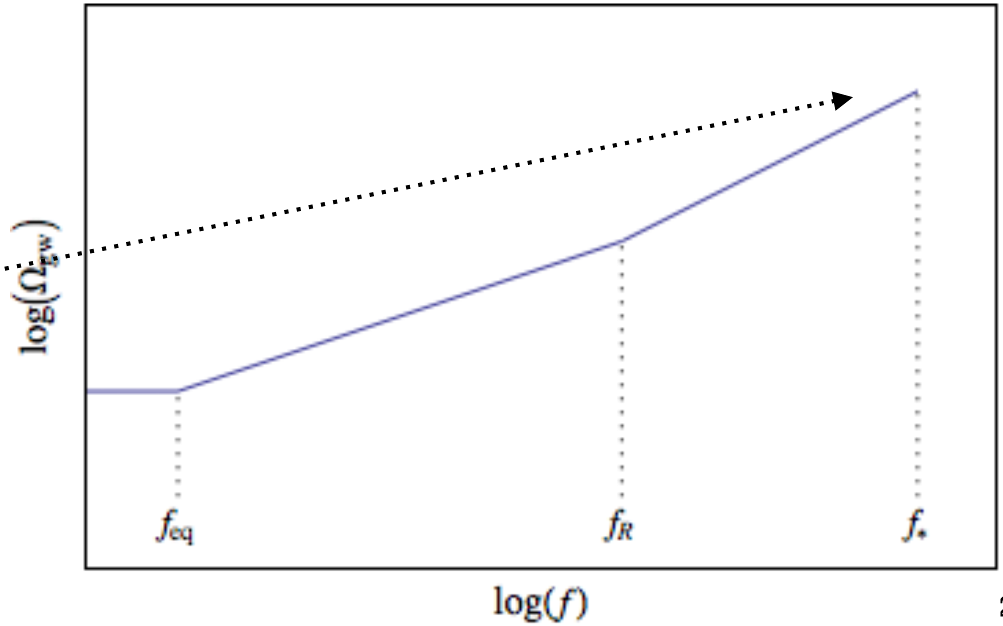
$$\mathcal{P}_\zeta \sim 10^{-9}$$

- gravitational waves

assume $T_R \sim 10^{10}\mathrm{GeV}$

$$\Omega_{gw} \sim 10^{-13}$$

$$f = 100\mathrm{MHz}$$



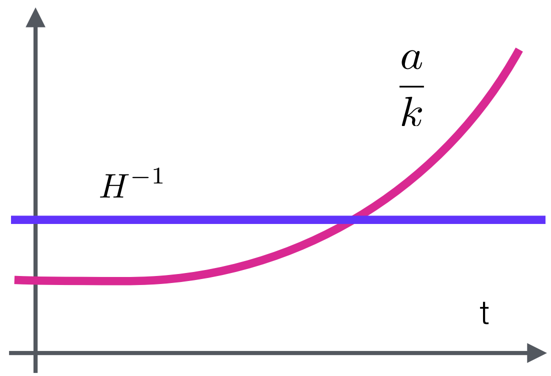
Inflation and Genesis

Background

Inflation

- Exponentially expansion.

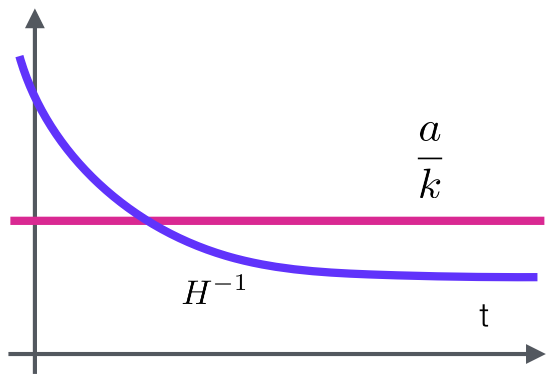
$$a(t) = a(t_i)e^{H_{inf}(t-t_i)}$$



Genesis

- Our universe started from Minkowski space-time.

$$a(t) \simeq 1 + \frac{1}{2\alpha}\frac{h_0}{(-t)^{2\alpha}} \quad (-\infty < t < 0)$$



$(\ t \to -\infty \ )$

Inflation and Genesis

Scalar perturbation

In many models of
Galilean Genesis, $\alpha=1$.
$\alpha=2$ in a few models.

Inflation

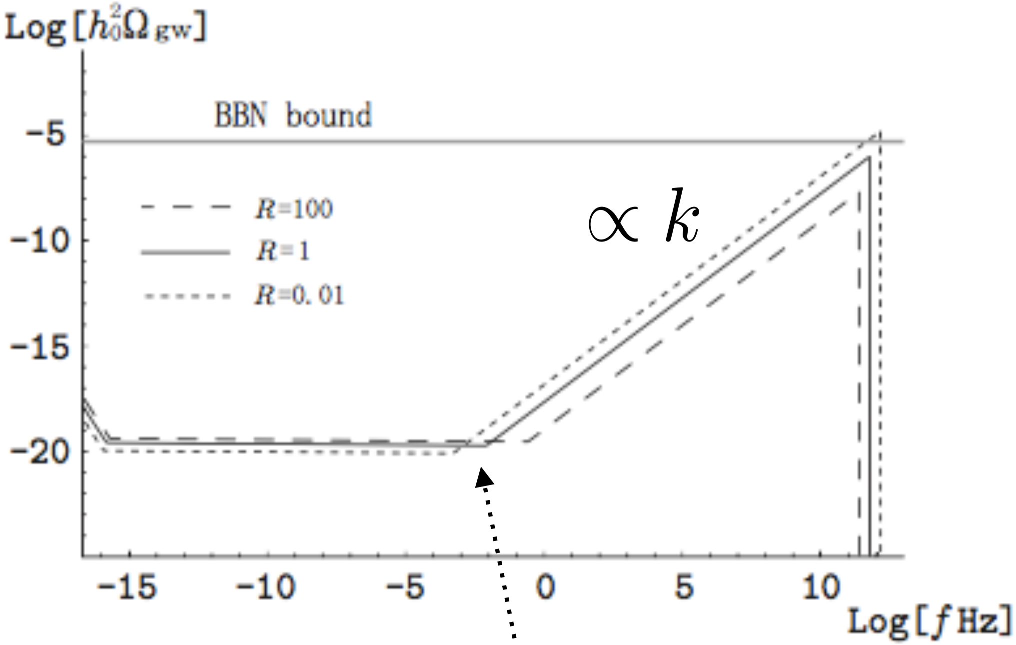
- Flat spectrum

Genesis

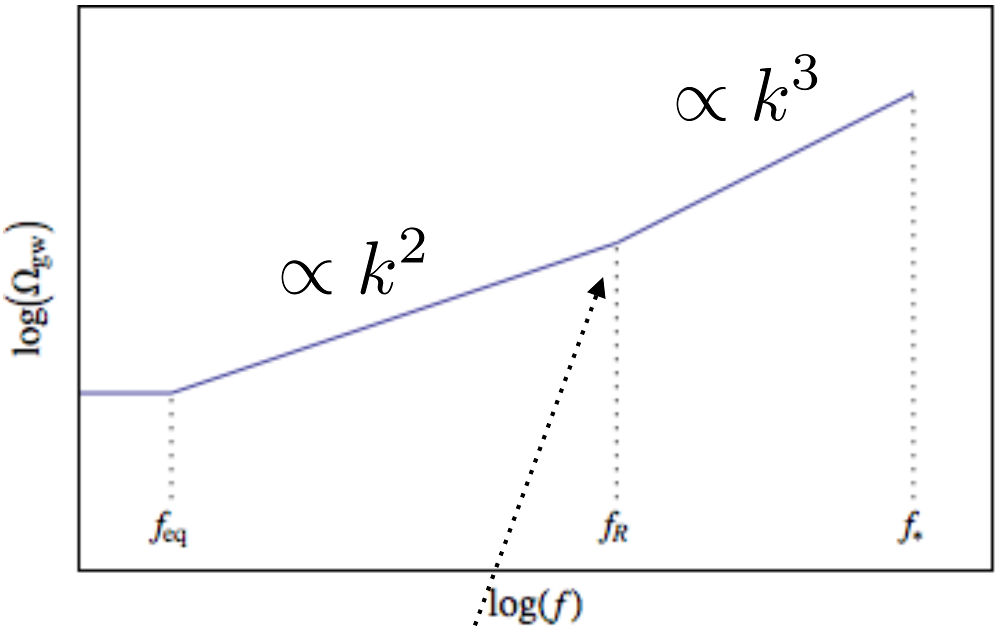
- $\alpha=2$ -> We obtain the flat spectrum without curvaton.

Inflation and Genesis

- Inflation
- Genesis



[H. Tashiro, T. Chiba, M. Sasaki, (2012)]



Ω_{gw}^{inf} can be larger than Ω_{gw}^{gen}

Conclusion

- H_* of genesis can be smaller than that of inflation.

- The shape of power spectrum is different between inflation and Genesis.

- We can find $\Omega_{gw} \sim 10^{-12}$ at $f = 100\mathrm{MHz}$ in any model of Genesis.